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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 :
B41B 15/00, B41J 15/00, 2/385, 2/435, G06F 15/00, H04N 9/802, G03G 15/01, 15/06, G01D 15/06, 15/14, G02F 1/13, 1/335

A1

(11) International Publication Number: WO 00/69631

(43) International Publication Date: 23 November 2000 (23.11.00)

(21) International Application Number: PCT/US00/11596

(22) International Filing Date: 1 May 2000 (01.05.00)

(30) Priority Data:
09/312,763 17 May 1999 (17.05.99) US

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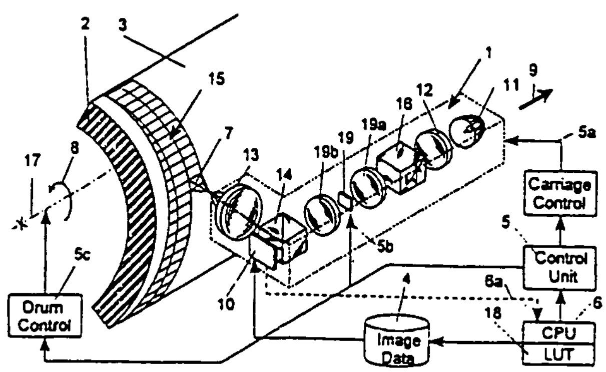
(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: DIGITAL IMAGE-SETTER UTILIZING HIGH-RESOLUTION MICRO-DISPLAY



(57) Abstract

A digital image-setter utilizing a micro-display (10) which produced, offset-printing plates with high print resolution and negligible smearing in an acceptably short time. The device, consisting of a drum (2) carrying a photo-sensitive offset printing plate medium (3) and an external, axially moving image projector (1), using a high-resolution, high-efficiency, reflective LC Spatial Light Modulator (SLM) as a micro-image source. The LC SLM is illuminated by a high-power, source of pulsed light (11) in the visible or near ultra-violet and the image is focused onto the photo-sensitive offset plate medium (3) by means of an optical projection system (13). On-the-fly adjustment may be made to the resolution of the final image. The source of pulsed light may be either a flash lamp or a continuous light source directed through a combination of two crossed, beam splitters (14, 16) and a polarization rotator (19). 98 % uniformity of illumination may be achieved by making use of the 64-level or more gray-scale capability of the SLM. Another version of the invention also utilizes auxiliary illumination material as that medium. All the components of the device are commercially available.

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DIGITAL IMAGE-SETTER UTILIZING HIGH-RESOLUTION MICRO-DISPLAY

FIELD AND BACKGROUND OF THE INVENTION

The present invention relates to production of offset-printing plates and, more particularly, to fast, digital image-setting to produce plates with high print resolution.

In recent years, the offset-printing industry has grown rapidly. The consequent demand for shortening the make-ready times of the offset plates and for enhanced quality has led to the development of fast, digital image-setters. This has resulted in Computer-To-Plate (CTP) imaging systems working with thermal or ablative offset plates based on near-infrared light sources such as YAG lasers and laser diodes.

However, offset plates sensitive in the near ultraviolet (UV) or visible (VIS) portion of the light spectrum continue to dominate the offset printing industry. These plates are imaged mainly by conventional technology involving several steps, including film preparation and subsequent plate exposure.

Designing a CTP system for UV or VIS printing plates has proved to be a rather difficult task, either because of the absence of a suitable laser source (in the UV case) or because of certain technological obstacles. For example, an external-drum CTP system based on a visible, single-beam, laser source such as a Frequency-Doubled Nd:YAG (532 nm) requires drum rotation speed of several thousand rpm in order to achieve acceptable imaging time; this is mechanically difficult. One possible approach to using such a light source is an internal-drum CTP that avoids the fast rotating drum. Such a plate-setter is commercially realized by AGFA of Germany – Galileo Visible Light Plate Manufacturing System. Another commercial system is Plate-setter 3244, made by CREO Products Inc. of Canada, in which an external-drum architecture is utilized. Both systems have the same disadvantage intrinsic to all laser-based systems: they can work only with media sensitive to the laser wavelength. The imaging time for 8-page format (32"×44") is comparable – 3 min for Platesetter 3244 and 4.28 min for AGFA's Galileo.

A possible approach to designing a CTP system working with a conventional (non-coherent) light source is to use a two-dimensional Spatial Light Modulator (SLM) as an image-forming device. Such an approach gives the advantage of using the broad spectrum of the light source so that the system is much less dependent on the type of image medium. The SLM is a one- or two-dimensional array of densely arranged optical modulators. Present SLMs, and particularly those based on Liquid Crystal (LC) technology, are rather slow devices, with refresh rates ranging from several tens to several hundreds of Hz. Therefore, the main problem in image-setter systems based on SLM is image smearing arising from and proportional to the relative speed between the medium and the imaging head and to the time during which the individual SLM's light modulators are open.

There are number of prior arts tackling the issue of imaging onto photo-sensitive media with the help of a two-dimensional (matrix) Liquid Crystal (LC) SLM.

- In US Pat. Nos. 4,859,034; 4,899,224; 5,050,001; 5,105,215; and 5,754,305 different configurations of LC SLM optical printing appliances are disclosed. One disadvantage of these systems is that no real on-the-fly imaging can be performed because the continuously operating light source results in noticeable image smearing. To avoid this, the relative speed between the imaging projection head and the photo-sensitive media has to be so low that imaging time is unacceptably long.

- One possible approach to avoiding image smearing is to design a machine working in step-and-repeat mode. This principle is used in UV-Setter® 710 and ProSetter CTPs produced by basysPrint GmbH of Boizenburg, Germany. These are flat-bed image-setters based on SLM working in transmission and a non-coherent UV light source. Because of the step-and-repeat principle of positioning the projection head, the imaging speed is quite low – 184 cm^2/min at 2540 dpi (100 dpm) resolution (ProSetter Technical Data Sheet). The imaging time for a full 8-up format (110 cm×90 cm) in this case is approximately 54 min.

- Another method of avoiding image smearing in on-the-fly image-setters working with two-dimensional SLMs and a continuous light source is described in US Pat. No. 5,132,723. The information on the SLM to be projected is consecutively shifted by one row in synchrony with the moving medium (or the imaging head). Thus, the imaged position of a particular row of information remains unchanged on the medium for a time determined by the medium sensitivity. This method is quite elegant, but minimizes the advantage of using a two-dimensional SLM, because the same row is repeated several times. The imaging speed is not much higher than can be achieved with linear array SLMs.

- US Pat. Nos. 5,675,368 and 5,745,156 describe LC matrix based "full-frame" printing devices utilizing a flashlamp as a light source. As the light pulse of the flashlamp is very short and powerful, the image on the medium appears without smearing, even at high relative speed. The SLM used is a relatively large (13" diagonal), low-resolution LC display working in transmission mode. It is the right choice for a "full-frame print" of small areas but, at the same time, has a significant drawback: the resolution of the display is some 10 lines/mm, which makes the system unusable for high-resolution, large-format image-setters.

Except for US 5,132,723, the above-cited prior art use, as SLM, an Active Matrix LC Display (AMLCD), working in transmission mode. These displays have an intrinsic disadvantage, making them unsuitable for high-resolution printing applications; a significant part of the pixel (*i.e.* picture element) area is occupied by the opaque active element. In order to have adequate energy transmission, the SLM pixel, therefore, needs dimensions of several tens to several hundred micrometers. But high-resolution digital printing requires on-the-medium spot dimensions of approximately 10 – 20 micrometers, so an AMLCD working in transmission mode requires optical reduction of the order of 10. The resulting small depth of focus renders such a system practically inapplicable for printing applications.

In a number of prior art patents, such as US Pat. Nos. 4,571,603; 5,041,851; and 5,049,901, a Digital Mirror Display (DMD) is used as a SLM (linear or matrix) in

conjunction with a continuous light source. These devices are very fast, highly efficient, and can provide on-the-fly imaging without smearing. On the other hand, because DMD SLMs are binary devices (pixels can be only open or closed), uniform exposure can be achieved either by using the approach of US 5,132,723, with the limitations described above, or to employ highly uniform illumination. Optical integrators can do this only to approximately 90% uniformity, which is adequate for binary photo-sensitive materials but not for VIS photopolymer printing plates, photographic film, or photographic paper.

There is thus a widely recognized need for, and it would be highly advantageous to have, a digital, high-speed, high-resolution, on-the-fly image-setter for offset printing plates, films and other photo-sensitive media, that overcomes the problem of smearing at high speed.

SUMMARY OF THE INVENTION

In recent years, due to the growing demand for high-resolution, high-brightness projection displays, rapid progress has been made in the development of reflective LC SLM technology. Especially notable is the advance in so-called "silicon back-plane" technology, leading to small, high-resolution, high-efficiency, reflective LC SLMs. Such SLMs (or as they are still called, micro-displays) can be used in conjunction with coherent or non-coherent light sources as a basis for a highly efficient CTP system for imaging of large-format, photo-sensitive media, in particular, offset printing plates.

According to the present invention there is provided a high-resolution, large-format, on-the-fly image-setter. The image-setter can be used for imaging offset lithography plates, large-format photographic films and paper, and other photo-sensitive media.

According to the present invention there is provided a digital image-setter for setting an image in a photo-sensitive medium including: (a) a drum for carrying the photo-sensitive medium and (b) an imaging head, external to the drum, for transferring the image onto the photo-sensitive medium, the imaging head including: (i) a source of

pulsed light; (ii) a reflective micro-image display operating as a spatial light modulator; (iii) a first optical mechanism for illuminating the micro-image display with the light pulses, and (iv) a second optical mechanism for projecting the light pulses reflected from the micro-image display onto the photo-sensitive medium.

According to the present invention, there is provided a method for continuously varying a dot resolution of a projected digital image including a plurality of pixels, including the steps of: a) providing: (i) a projective source of the digital image having a certain resolution, and (ii) an optical projection system having a variable magnification; and b) simultaneously: (i) grouping contiguous pixels of the source into arrays of macro-pixels, and (ii) varying the magnification of the projection system, so as to provide a continuous range of the dot resolution.

According to the present invention, there is provided, in a system for projecting a digital image wherein the digital image is formed by reflecting incident light from a matrix of discrete pixels of individually variable reflectivity, a method for correcting for non-uniform illumination and for non-uniform reflectivity among the pixels including the steps of: a) calibrating the matrix in combination with the incident light, thereby obtaining correction data, and b) correcting for non-uniformity in the illumination and in the reflectivity of the pixels when projecting the image by varying the reflectivity in accordance with the correction data.

According to the present invention, there is provided a method for projecting an image onto a photo-sensitive medium, including the steps of: a) mounting the photosensitive medium on a cylindrical drum; b) partitioning the image into a plurality of micro-images; c) providing a mechanism for projecting the micro-images onto the photo-sensitive medium; and d) projecting the micro-images sequentially onto the photosensitive medium, using the mechanism, while moving the mechanism relative to the drum, each the projecting being effected for a period of time that restricts a smearing of the micro-image on the photo-sensitive medium to within a predefined tolerance.

The present invention discloses an innovative use of a pulsed light source in combination with a high-resolution, high-efficiency, reflective micro-display to address the shortcomings of the presently known configurations. The present invention successfully achieves seamless construction of an image on a photo-sensitive medium in sufficiently short time, with negligible smearing, and at sufficiently high resolution to serve the printing industry's needs. All components are commercially available.

According to the present invention there is provided a control system including: an image data store wherein the image is stored digitally in micro-frames, sub-image matrices corresponding to the pixels of the LC Spatial Light Modulator, and from which sub-image matrices are transferred to the micro-display as required; a control unit which precisely governs drum rotation speed, imaging head motion, and light-pulse timing so as to provide seamless imaging; a look-up table that enables digital correction for non-uniform illumination by controlling the reflectance gray-scale of the micro-display; and a CPU which governs all of these components and actions; and in conjunction with which precision timing is employed to construct high-resolution, seamless images with negligible smearing;

According to the present invention, when a specific micro-image is loaded into the micro-display's electronic drivers, the latent sub-image so created in the LC medium is then illuminated through the first set of optics with light pulses from the pulsed light source, and imaged onto the photo-sensitive medium by the second set of optics.

According to still further features in the described preferred embodiments, reflectivity is varied by activating the gray-scale capabilities (minimum 64 levels of gray) of each pixel of the micro-display according to the look-up table.

According to the present invention, the projection optics is telecentric on the image side and with sufficient focal depth to minimize the pincushion distortion resulting from the drum's curvature.

According to still further features of the invention, the drum rotation speed, the imaging head's linear speed, the micro-frame data loading, and the light pulses are so synchronized that the final image on the photo-sensitive medium is seamlessly built-up from the consecutive sub-images in accordance with the image data and with negligible smearing.

According to one embodiment of the present invention, a high-energy flashlamp is used as a pulsed light source.

According to another, preferred embodiment, a high-power, continuous light source, working in conjunction with a fast electro-optic polarization rotator, such as a PLZT (Lead – Lanthanum – Zirconate – Titanate) optical shutter, is used as a pulsed light source.

According to another embodiment of the present invention, auxiliary illumination of the image medium is employed to enable the use of high-contrast digital photo-sensitive media, which are typically characterized by low light sensitivity.

The use, in the present invention, of commercially available components and the employment of easily achieved high-precision electronic timing instead of high-precision mechanical components, means that the invention disclosed is economical.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is herein described, by way of example only, with reference to the accompanying drawings, wherein:

FIG. 1 is a schematic isometric view of the disclosed image-setter using a flashlamp as a light source;

FIG. 2a is an exemplary diagram showing the timing of processes involved in production of sub-images on the photo-sensitive medium when the light source is a flashlamp;

FIG. 2b is an exemplary diagram showing the timing of processes involved in production of sub-images on the photo-sensitive medium when the light source is a continuous one working in conjunction with a fast PLZT shutter;

FIG. 3 schematically illustrates the composition of the entire image by seamlessly fitting sequential sub-images helically;

FIG. 4 schematically illustrates the composition of the entire image by seamlessly fitting sequential sub-images axially;

FIGs 5a, 5b, and 5c illustrate different ways of changing the print resolution of the disclosed embodiments; and

FIG. 6 is a schematic isometric view of the disclosed image-setter using a high-power continuous light source working in conjunction with a fast optical shutter to form a pulsed light source.

FIG. 7 shows the light sensitivity exhibited by binary photo-sensitive media and how auxiliary, sub-threshold illumination can be employed in image forming to overcome low light sensitivity of such media.

FIG. 8 illustrates the imaging section of the invention shown in FIG. 1 but also incorporating an auxiliary background illumination for use when imaging onto binary photo-sensitive materials.

In the accompanying drawings, the same reference numerals refer to the same parts throughout the figures of the drawing

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is of a digital image-setter utilizing a high-resolution micro-display which can be used to project an image seamlessly constructed from sequential sub-images in a reasonably short time and of high resolution. Specifically, the present invention can be used to produce plates for offset printing.

The principles and operation of the image-setter according to the present invention may be better understood with reference to the drawings and the accompanying description.

Referring now to Figure 1, which is a schematic isometric view of one preferred embodiment of the image-setter of the present invention, a photo-sensitive medium **3** is wrapped around a cylindrical drum **2**. Drum **2** rotates with constant angular speed in the direction indicated by arrow **8**. A projection head **1**, moves parallel to the axis **17** of drum **2**, in the direction indicated by arrow **9**.

Projection head **1** includes a source of pulsed light **11** (in this case a flashlamp), light collecting, integrating and illuminating optics **12**, a reflective, high-efficiency, high-resolution micro-display **10**, a polarizing beam splitter **14**, and a projection lens **13**. The construction of projection head **1** as a whole resembles the construction of a projection display. There is, however, a major difference in that the magnification of projection lens **13** is close to 1, (the corresponding magnification of a projection display would be several hundreds). (Detailed analyses of the properties of projection displays and methods of calculating their parameters can be found in *Fundamentals of Projection Displays* SID '98 Short Course, Matthew S. Brenneholtz, SID 1998.)

Micro-display **10** is a matrix array of P×Q LC optical modulators working in reflective mode. The matrix array may be, for example, a Ferroelectric LCD such as LPD-1310-PV1 from Displaytech, CO, or Twisted Nematic LCD from IBM Display Business Unit, Japan (*High Information-Content Projection Display Based on Reflective LC on Silicon Light Valves*, SID 1998 Proceedings, p.25). The matrix array works as a write-only memory and incorporates the frame buffer and all necessary electronic drivers to change the electro-optical state of the LC in accordance with the image data.

Most commercially available SLMs have an aspect ratio P:Q = 4:3 (SVGA and XGA formats) or 5:4 (SXGA format). Under certain illumination and imaging conditions, it is best to use, not the full matrix of P×Q pixels, but only part of it with dimensions $P1 \times Q1$, where $P1 \leq P$ and $Q1 \leq Q$. For example, it is easier to design a projection lens

with corrected distortions when the SLM aspect ratio is substantially greater (or smaller) than 1, i.e. $P1 \leq P$ and $Q1 \ll Q$ (or $P1 \ll P$ and $Q1 \leq Q$). A useful advance in this regard is the rapidly developing HDTV format micro-display, with aspect ratio 16:9.

The image to be printed on photo-sensitive medium **3** is stored in digital format in a system memory **4**. The data information is divided into a certain number of micro-frames as digital matrices, each with dimension p×q. Each micro-frame matrix consists of substantially the same number of numerals as the number of the pixels in the working part of the micro-display, and has substantially the same aspect ratio as the working part of the micro-display, *i.e.* $p = P_1$ and $q = Q_1$.

A CPU **6** loads micro-frame matrix information, in accordance with the image data in **4**, into micro-display **10**'s buffer. The LC changes its electro-optical state, forming a latent image in micro-display **10**. After the latent image is formed, a control unit **5** issues a signal **5b** to flashlamp **11**, which produces a short, powerful pulse of light. The light is collected and spatially shaped by collecting, integrating and illuminating optics **12** and polarized by beam splitter **14**. Thus, the micro-display active area is illuminated with a quasi-uniform field of polarized light only for the short period of the flash. Figure 2a shows the timing of the processes.

Optionally, an "image ready" feedback **6a** is provided. Under this option, signal **5b** does not immediately follow the "image ready" feedback signal. Rather, as it will be explained below, the timing of signal **5b** is calculated according the drum speed, in order to achieve seamless fitting of contiguous sub-images **7**. Thus, the seamless composing of an entire image **15** is due to precise timing of initiating signal **5b** in accordance with the rotation speed of drum **2** and the carriage-advance speed of projection head **1**.

The individual pixels (modulators) of the micro-display **10** reflect light with varying polarization, determined by the data loaded in micro-display **10**'s buffers. This polarization modulation of the light is then transformed into amplitude modulation and directed to projection lens **13** by polarizing beam splitter **14**. Projection lens **13** is

focused onto photo-sensitive medium **3**, with focal correction to compensate for drum 2 curvature. In accordance with the desired image resolution, projection lens **13** creates magnified or reduced (*i.e.* magnification <1) real image 7 of micro-display **10** on photo-sensitive medium 3. Image 7 of micro-display **10** is thus a sub-image of image **15** to be printed on photo-sensitive medium 3. In other words, image **15** is composed of seamlessly fitted "light stamps" on photo-sensitive medium **3**. In this way, the micro-display may be said to act as a digital image source.

CPU **6**, through control unit **5**, controls rotation speed (**5c**) of drum **2**, advance speed (5a) of projection head 1, and timing of the flash (**5b**). Control is such that the entire image **15** on photo-sensitive medium 3 is composed by seamlessly fitting a sequence of sub-images 7. The sequence of sub-images 7 on drum 2 forms a helix, schematically illustrated in Figure 3. Arrow **8** indicates the rotation direction of drum 2 around its axis **17** and arrow **16** indicates the development of the helix on medium **3**. Numbers **71a** to **71e** indicate the first five sub-images of the first cycle of the helix, numbers **72a** to **72e** indicate the first five sub-images of the second cycle of the helix, and so on. It is clear that, in order to build the helix, not all of the sub-images are full-framed. The first and last cycles of the helix are built from partially framed sub-images, as illustrated in Figure 3. It is possible also, that sub-images **71n**, **72n**, *etc.*, adjacent to the image end-line might also be partially framed, as illustrated in the figure. The sub-frame digital matrices corresponding to partially framed sub-images are also only partially filled with image information; the remainder of these matrices is filled with zeros. In the described scheme for composing the image, projection head 1 makes only one pass from left to right (arrow 9). In that time, drum **2** makes $N = \mathrm{Int}\left({}^{L}\!/_{L_0}\right) + 1$ rotations, where L is the length of the composed image, and L_0 is the length of each sub-image.

As well as the helical method of image composition described in the previous paragraph, other ways of composing the final image are also possible. For example, in an alternative embodiment of the image setter of the present invention, axial composition is effected: drum 2 makes only one rotation for the whole process, while

projection head **1** makes many shuttle-like back and forth passes. In this case, the final image is composed of sequentially built axial rows of sub-images, as illustrated in Figure 4. Arrow **9** indicates the motion of projection head **1**. Arrow **16** indicates the development of each row of sub-images. The first and last rows might consist of incomplete sub-image frames – **71a**, **71b**, ..., due to rotation of drum **2**. The first and the last sub-images in each row might also consist of incomplete frames – **72a**, **73a**, ..., **71n**, **72n**, ...

An important parameter of a digital printing machine is the print resolution, expressed in dots-per-millimeter (dpm). A distinction should be made between print resolution and the resolution of the micro-display. The micro-display resolution is expressed as total number of pixels (optical modulators) per device – 1024×768, 1200×1024, *etc.*, or as a pixel pitch in micrometers. The sub-image that the micro-display produces on the medium has the same number of print dots (P1×Q1) as the number of the pixels of the working part of the micro-display, and the same aspect ratio (P1:Q1). The density of these dots expressed in dpm determines the print resolution. In other words, the print resolution R depends on the micro-display resolution R_d and the magnification M of imaging lens **13**.

In the disclosed image-setter, the print resolution can be changed in two ways: by grouping a number of pixels of the SLM into a macro-pixel, and by using an imaging lens with variable magnification M. The print resolution can be expressed as $R = M \times \frac{1000}{R_d[\mu m]} \times \frac{1}{n}[\text{dpm}]$, where n^2 is the number of pixels grouped in a macro-pixel.

Grouping contiguous pixels into macro-pixels provides a stepwise change in the print resolution. Figure 5a illustrates a print cell **20** with dot-percentage 50 (gray level of 50%), composed of 16×16 print dots. Each print dot **21** on medium **3** corresponds to an image **23** of only one open pixel (n = 1) of micro-display **10**. If the magnification M_1 of imaging lens **13** (Figure 1) is such that the micro-display's pixels imaged on the medium produce dots with pitch 10 μm (0.01mm), then print cell **20** in Figure 5a is

composed with print resolution 100 dpm. For clarity, images **22** of micro-display **10**'s closed pixels (those not producing print dots) are also shown in the figure.

Figure 5b presents the same print cell **20** with dot-percentage 50, as in figure 5a, but composed of 8×8 dots each formed by grouping four micro-display pixels into one macro-pixel, while keeping the optical magnification constant M_1. Each print dot **21** corresponds to the images of four open pixels (n=2) of micro-display **10**. The print dot pitch in this case is 20 μm (0.02mm) and, hence, print cell **20** is composed with dot resolution 50 dpm. The described way of changing the print-dot resolution in steps is especially convenient. So long as the optical magnification M is constant, the energy density projected onto medium **3** also remains constant and hence no change in the power of the light pulses is required when changing the print resolution in this way. This method of changing print-dot resolution may be done on the fly, i.e. different parts of the same image can be imaged with different resolution. Moreover, different parts of the same micro-image can be built up with different resolutions.

By changing the magnification M of projection lens **13** (Figure 1) and adding additional pixels in composing print cell **20**, any print resolution between the two illustrated in Figures 5a and 5b may be achieved. An example is presented in Figure 5c. If the magnification of projection lens **13** is $M_2 = 0.75M_1$ and n=2, the micro-display's pixels produce dots with pitch 7.5 μm (0.0075mm). The number of print dots 21 composing print cell 20 in this case is 12×12, with pitch 15 μm (0.015mm), and hence the print resolution is 75 dpm. It is seen that, by suitably varying M and number of micro-display pixels, a range of print resolutions is achievable. This method of varying resolution by a step-wise variation of the number of micro-display pixels forming each macro-pixel in conjunction with varying projection magnification so as to produce an overall smoothly varying resolution is a significant and advantageous innovation. To illustrate the point, if one used only a variable lens, then a resolution change by a factor of 3 would require a magnification change of the same value, which places quite stringent demands on the lens. In the present invention, the combination can be achieved by a step of 2 and a magnification change of only 1.5, which places a less stringent requirement on the lens.

An important element of projection head **1** is collecting, integrating and illuminating optics **12**. Optics **12** incorporates a so-called optical integrator, to transform the circular light field from light source **11** into a quasi-uniform rectangular light field, with aspect ratio close to the aspect ratio of micro-display **10**. (Analyses of different types of optical integrators can be found in *Fundamentals of Projection Displays*, SID '98 Short Course, Matthew S. Brenneholtz, SID 1998.) Currently available integrators can achieve some 90% uniformity in the light field illuminating micro-display **10**. Although the disclosed image-setter is digital, *i.e.* all micro-display pixels work in binary mode (open or closed), this level of uniformity is not sufficient for many graphic arts applications (such as photographic film imaging). In the preferred embodiments of the present invention, optional correction of the non-uniform illumination of micro-display **10** is achieved by using the gray-scale capabilities of each pixel of micro-display **10**. Most contemporary LC micro-displays, including those of IBM cited above, can provide a minimum of 64 gradations of gray, from black to white, for each pixel, so correction of the light field to a uniformity of at least 98% can be made. Correction for non-uniform reflectivity among pixels may also be made in this manner. For this purpose, after the projection head is assembled (or after replacing the light source), a measurement of the light field uniformity is made by means well known in the art. Such calibration, for both non-uniformity of illumination and non-uniformity of pixel reflectivity, is performed for each given combination of light source and micro-display to obtain correction data. From the results of this calibration, a Look-Up-Table (LUT) **18** (Figure 1) is constructed. Then, when loading the image data into the micro-display buffers, for all open pixels the corresponding values from the LUT **18** are applied.

Magnification M and depth of focus d_M are important parameters of imaging lens **13**. The required magnification M is calculated from the chosen micro-display pixel pitch and the desired resolution. If, for example, the micro-display is of type LPD-1310-PV1 from Displaytech, CO., with pixel pitch 13.2 μm, and the desired print resolution is 100 dpm, then the required optical magnification is $M \cong 0.76$. If the imaging lens is telecentric (i.e. one whose chief rays are substantially parallel to each other and, usually, to the optic axis) on the image side, an axial shift in the receiving surface

results in defocusing but preserves the image proportions and scale. Thus, pincushion distortion due to the drum's curvature may be eliminated. Pixel image blurring (defocusing) depends upon the depth of focus; by designing the lens with sufficient depth of focus, the problem of image defocusing is solved. The required depth of focus d_M depends on the diameter D_d of drum 2 (Figure 3), the mechanical accuracy of the system, and the thickness accuracy of the photosensitive medium.

An important property of the image-setter is the shorter imaging time that can be achieved for a specific photo-sensitive medium format. This time depends on the power and maximum flash rate at a given discharge energy of light source 11 (Figure 1). For example, flashlamp FX 1150 from EG&G, MA, with average power 20 W and maximum flash rate 300 Hz, has a flash duration of 2 μs, with flash jitter 200 ns. Other pulsed light sources, such as laser diodes, bars, or Q-switched lasers, can be also be used. Let us consider that photo-sensitive medium 3 to be imaged is photopolymer offset plate type N90A from Agfa, with dimensions L×H = 44"x32". This plate is sensitive in the range 400 nm – 550 nm, with sensitivity 150 $\mu J/cm^2$. The area of the LPD-1310-PV1 image on photo-sensitive medium 3 is 1.31 cm^2 at 100 dpm print resolution. Analysis of the optical system energy efficiency, made by means well known in the art, and flashlamp efficiency (EG&G Flashlamps Catalog) show that a 140 mJ discharge energy is needed to image this surface with one flash. As the flashlamp average power is 20 W, the maximum flash rate at 140 mJ discharge energy is 140 Hz. Further analysis shows that, for 350 mm diameter of drum 2, the rotational speed is 80 rpm and the imaging time for the N90A plate is approximately 66 s. This short imaging time at low drum rotational speed clearly indicates the advantage of the disclosed embodiment.

Knowing the drum rotation speed, 80 rpm, and the flash pulse width, 2 μs, it easy to estimate that the expected image smearing will be less than 3 μm. Such small image smearing is more than acceptable for most graphic arts applications.

It is important to emphasize that light sources 11 with as small as possible pulse jitter should be used. Pulse jitter contributes directly to the gaps between sub-images 7 in the process of composing the entire image 15. For example, a pulse jitter of 200 ns

(as for the FX 1150) contributes approximately 0.3 μm to the error in sub-image fitting at 80 rpm drum rotation speed.

An alternative, preferred embodiment of the present invention is shown in Figure 6, wherein light source **11** is in continuous operation. This embodiment includes an additional beam-splitter cube **16** and a fast electro-optical polarization rotator **19**.

The combination of two crossed, beam splitters with polarization rotator between them works as a fast, electrically controllable, optical deflector, well known in the art. Light from light source **11** is collected and spatially shaped by collecting, integrating, and illuminating optics **12**, and polarized by polarizing beam splitter **16**. In the passive state, electrically controllable, fast polarization rotator **19** has no effect on the polarization of the light, which is reflected by the second polarizing beam splitter **14**. In the active state, polarization rotator **19** rotates the polarization of the light by 90° and, hence, transmitted by the second polarizing beam splitter **14** towards micro-display **10**. Polarization rotator **19**, may be, for example, an electrically controllable PLZT retardation plate, well known in the art. Lenses **19a** and **19b** respectively narrow and then expand the optical beam. Thus, smaller PLZT crystals driven by lower voltage pulses can be used (J. T. Cutchen *et al, PLZT electro-optic shutters: applications*, Appl. Optics 14, 1866-1873 (1975)).

CPU **6** loads micro-frame information representing image data **4** into micro-display **10**'s buffer frame. The electro-optical state of the LC changes forming a latent image in micro-display **10**. During loading the information and forming the latent image, polarization rotator **19** is in the passive state and micro-display **10** is not illuminated. After the latent image is formed, control unit **5** changes the state of the polarization rotator **19** to active for a short period. The light is reflected by polarizing beam splitter **14**, and thus micro-display **10**'s active area is quasi-uniformly illuminated with polarized light for a short period. Figure 2b shows the timing of the process.

The individual pixels (modulators) of micro-display **10** reflect light with varying polarization, corresponding to the data loaded into micro-display **10**'s buffers. This polarization modulation of the light is then transformed into amplitude modulation

and directed to projection lens 13 by polarizing beam splitter 14. Projection lens 13 is focused onto photo-sensitive medium 3. Depending on the desired image resolution, projection lens 13 creates a magnified or reduced real image 7 of micro-display 10 on photo-sensitive medium 3 as before. Image 7 of micro-display 3 is thus a sub-image of entire image 15 to be printed on the photo-sensitive medium 3. (Other details are as for the embodiment first described.)

A further embodiment of the invention enables the use of binary, pre-sensitized, photo-sensitive image media. The advantages of using such media include their high contrast (high gamma) in comparison with analogue media, which are low contrast, the convenience of using a digital means to obtain the final printed image, and their cheaper cost as compared with analogue plates. Their disadvantage is the relatively high energy-density threshold to be passed before changes take place in the media structure; very high powered pulsed sources of illumination are usually required to imprint images on such materials. A typical example is the conventional, UV-sensitive (around 400nm), offset printing plate. To image such plates by use of the embodiments in Figure 1 or Figure 2 would require a pulsed UV light of very high power and small emitting volume (to produce a high-quality beam), two rather contradictory requirements for non-coherent light sources.

The sensitivity of such materials is illustrated in Figure 7. The upper part of the graph shows an exemplary D—logH curve (solid line) of a binary photo-sensitive material. D is the optical density of the exposed parts of the medium and logH is the base-10 logarithm of the exposure (irradiance × time). In the figure, a typical D—log H curve for an analogue photo-sensitive material (dashed line) is also shown, for comparison. The important property shown in the graph is the very steep linear part of the curve and well-defined "shoulder". It may be seen that, for exposures lower than the curve's "toe", there is no significant change in D but, for energy densities above the threshold represented by the steep ascent, the change in D is significant. The threshold for each type of binary material must be determined experimentally.

One way to solve the problem of the high energy density needed to surpass the threshold is to use an auxiliary, spatially quasi-uniform illumination just below the

threshold and to apply, on top of it, additional light pulses to exceed the threshold only at those points where an imprint is desired. Thus the total illumination is sufficient to surpass the threshold only at those locations where imaging is required. The process is illustrated on the lower part of Figure 7.

This is the approach employed in the further embodiment illustrated in Figure 8, which shows projection head **1** of Figure 1 augmented by pre-sensitizing illuminating head **1a**. Light from a high-energy light source **11a** is collected and spatially shaped by optics **12a** and directed onto photo-sensitive medium **3**. This light illuminates part of photo-sensitive medium **3** to be imaged substantially constantly and uniformly so as to provided the required sub-threshold level of exposure. In addition, the same part of photo-sensitive medium **3** is illuminated with spatially modulated, relatively low-energy light pulses produced by projection head **1**, as described above. The total exposure on parts of photo-sensitive medium **3** corresponding to open pixels of micro-display **10** reaches levels above the threshold and results in changes of the optical density of the material. Likewise, the total exposure on parts of photo-sensitive medium **3** corresponding to closed pixels of micro-display **10** remains below the threshold and no change in the optical density of the material results. Thus the image projected by projection head **1** acts as a trigger for imaging to take place on the pre-sensitized photo-sensitive medium **3**. Pre-sensitizing illuminating head **1a** can be designed as an addition that moves together with projection head **1**.

Because the quality demanded of the pre-sensitizing auxiliary illumination (as regards spatial homogeneity and focusing) is much lower than that of the imaging beam, light source **11a** can have a larger emitting volume than is possible for light source **11**. Thus a high-power flash lamp working in synchrony with light source **11** may be used for this purpose; alternatively, high-power continuous illumination may be used.

While the invention has been described with respect to a limited number of embodiments, it will be appreciated that many variations, modifications and other applications of the invention may be made.

WHAT IS CLAIMED IS

1. A digital image-setter for setting an image in a photo-sensitive medium comprising:

   a) a drum for carrying said photo-sensitive medium; and

   b) an imaging head, external to said drum, for transferring said image onto the photo-sensitive medium, said imaging head including:

      i) a source of pulsed light;

      ii) a reflective micro-image display operating as a spatial light modulator;

      iii) a first optical mechanism for illuminating said micro-image display with said light pulses, and

      iv) a second optical mechanism for projecting said light pulses reflected from said micro-image display onto at least a portion of said photo-sensitive medium.

2. The digital image setter of claim 1 further comprising:

   (c) a control system for governing:

      i) relative motion of said drum and said imaging head by controlling rotation of said drum about an axis of symmetry thereof and motion of said imaging head parallel to said axis of symmetry, and

      ii) operation of said source of pulsed light.

3. The digital image setter of claim 1, wherein said reflective micro-image display has a controllable reflectivity, the digital image setter further comprising:

   (c) a control system for governing:

      i) operation of said source of pulsed light and

ii) reflectivity of said micro-image display.

4. The digital image setter of claim 3 wherein said reflectivity is controlled according to a look-up table specific to said light source and to said micro-image display.

5. The digital image setter of claim 1 wherein said reflective micro-image display includes pixels having individually controllable, variable reflectivity.

6. The digital image setter of claim 4 wherein said reflective micro-image display includes a two-dimensional, liquid-crystal micro-display.

7. The digital image setter of claim 1, wherein said source of said light pulses includes a flash lamp.

8. The digital image setter of claim 1, wherein said source of said light pulses includes:

a) a source of continuous light; and

b) a mechanism for alternately blocking and passing said continuous light.

9. The digital image setter of claim 8, wherein said mechanism for alternately blocking and passing said continuous light includes:

a) a first polarizing beam splitter,

b) a second polarizing beam splitter, and

c) a polarization rotator between said first and second polarizing beam splitters.

10. The digital image setter of claim 1 further comprising:

(d) an illumination head, external to said drum, for illuminating said portion of said photosensitive medium along with said imaging head.

11. The digital image setter of claim 10, wherein said illumination head includes a flash lamp.

12. The digital image setter of claim 10, wherein said illumination head includes a source of continuous illumination.

13. A method for continuously varying a dot resolution of a projected digital image including a plurality of pixels, comprising the steps of:

    a) providing:

        (i) a projective source of the digital image having a certain resolution, and

        (ii) an optical projection system having a variable magnification; and

    b) simultaneously:

        (i) grouping contiguous pixels of said source into arrays of macro-pixels, and

        (ii) varying said magnification of said projection system,

    so as to provide a continuous range of the dot resolution.

14. In a system for projecting a digital image wherein the digital image is formed by reflecting incident light from a matrix of discrete pixels of individually variable reflectivity, a method for correcting for non-uniform illumination and for non-uniform reflectivity among the pixels comprising the steps of:

    a) calibrating the matrix in combination with the incident light, thereby obtaining correction data, and

    b) correcting for non-uniformity in said illumination and in said reflectivity of said pixels when projecting said image by varying said reflectivity in accordance with said correction data.

15. The method of claim 14 wherein said correction data is stored in a look-up table.

16. A method for projecting an image onto a photo-sensitive medium, comprising the steps of:

    a) mounting said photosensitive medium on a cylindrical drum;

    b) partitioning said image into a plurality of micro-images;

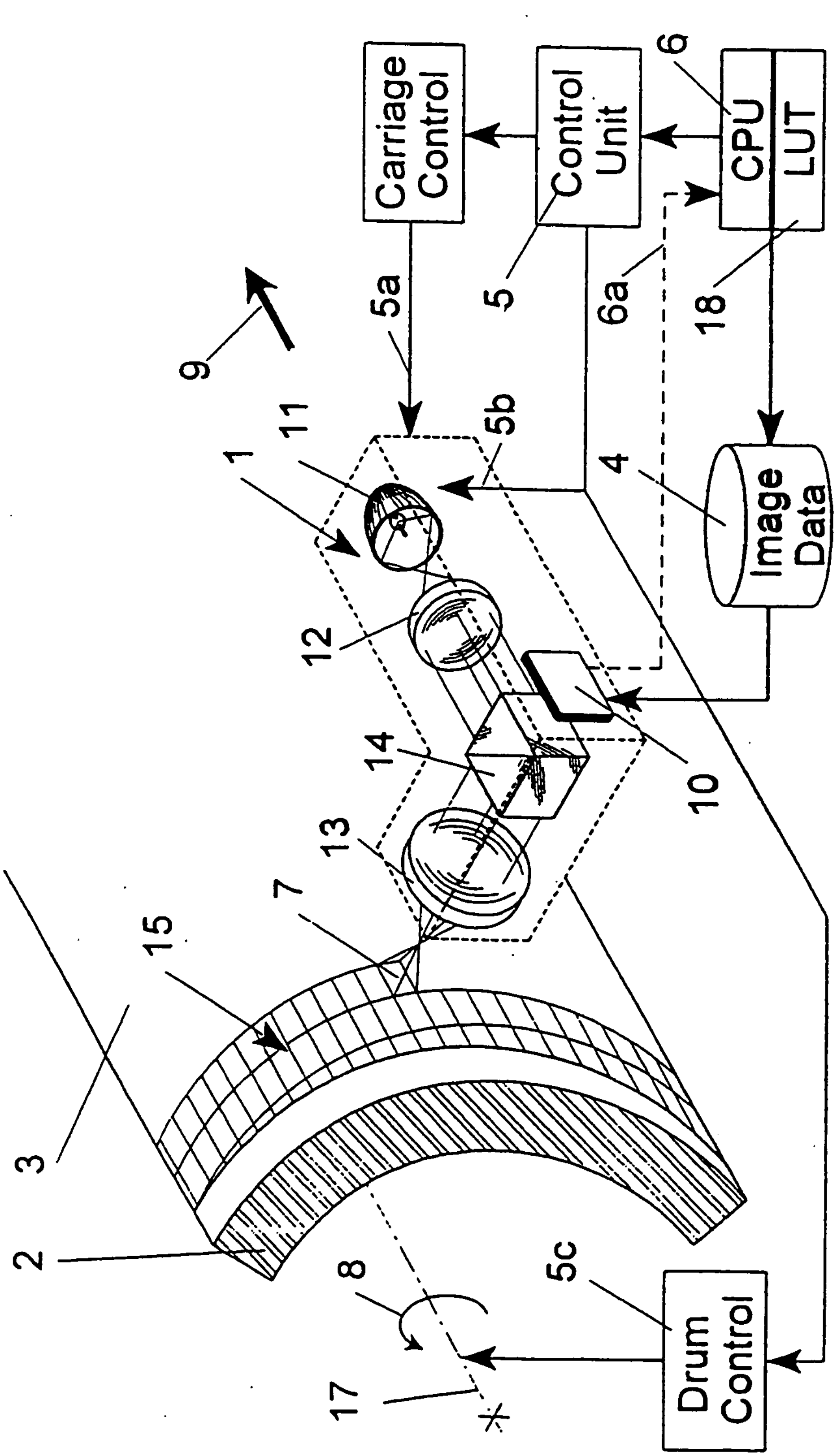
    c) providing a mechanism for projecting said micro-images onto said photo-sensitive medium; and

    d) projecting said micro-images sequentially onto said photosensitive medium, using said mechanism, while moving said mechanism relative to said drum, each said projecting being effected for a period of time that restricts a smearing of said micro-image on said photo-sensitive medium to within a predefined tolerance.

17. The method of claim 6 wherein said drum rotates and said projecting mechanism moves parallel to a rotational axis of said drum.

18. The method of claim 7 wherein said rotating and moving is such that said image is composed helically.

19. The method of claim 17 wherein said rotating and moving is such that said image is composed axially.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CPU
LUT
Image Data
Drum Control
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2
3
4
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18

Figure 1

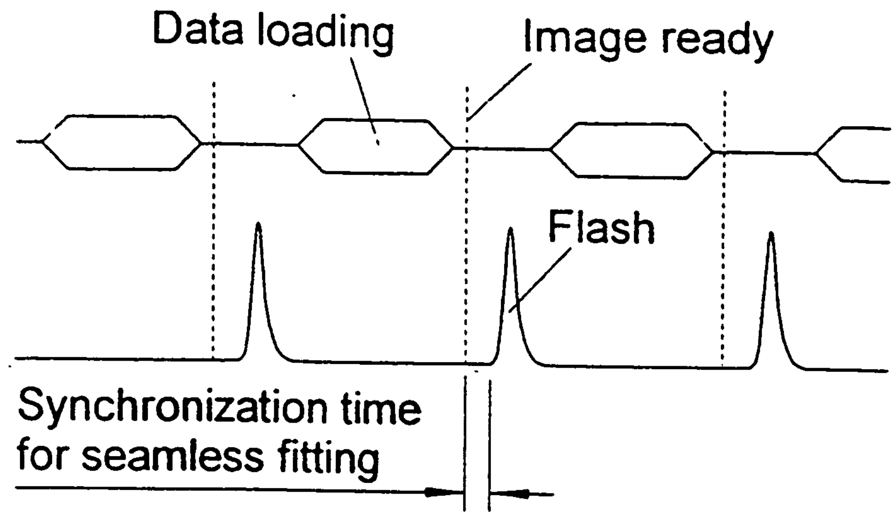


Figure 2a

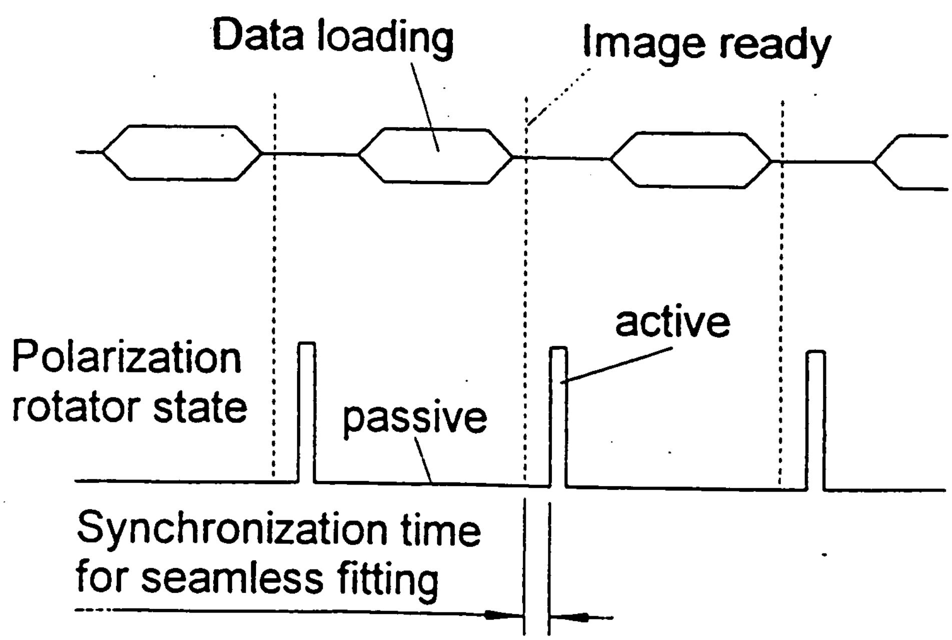
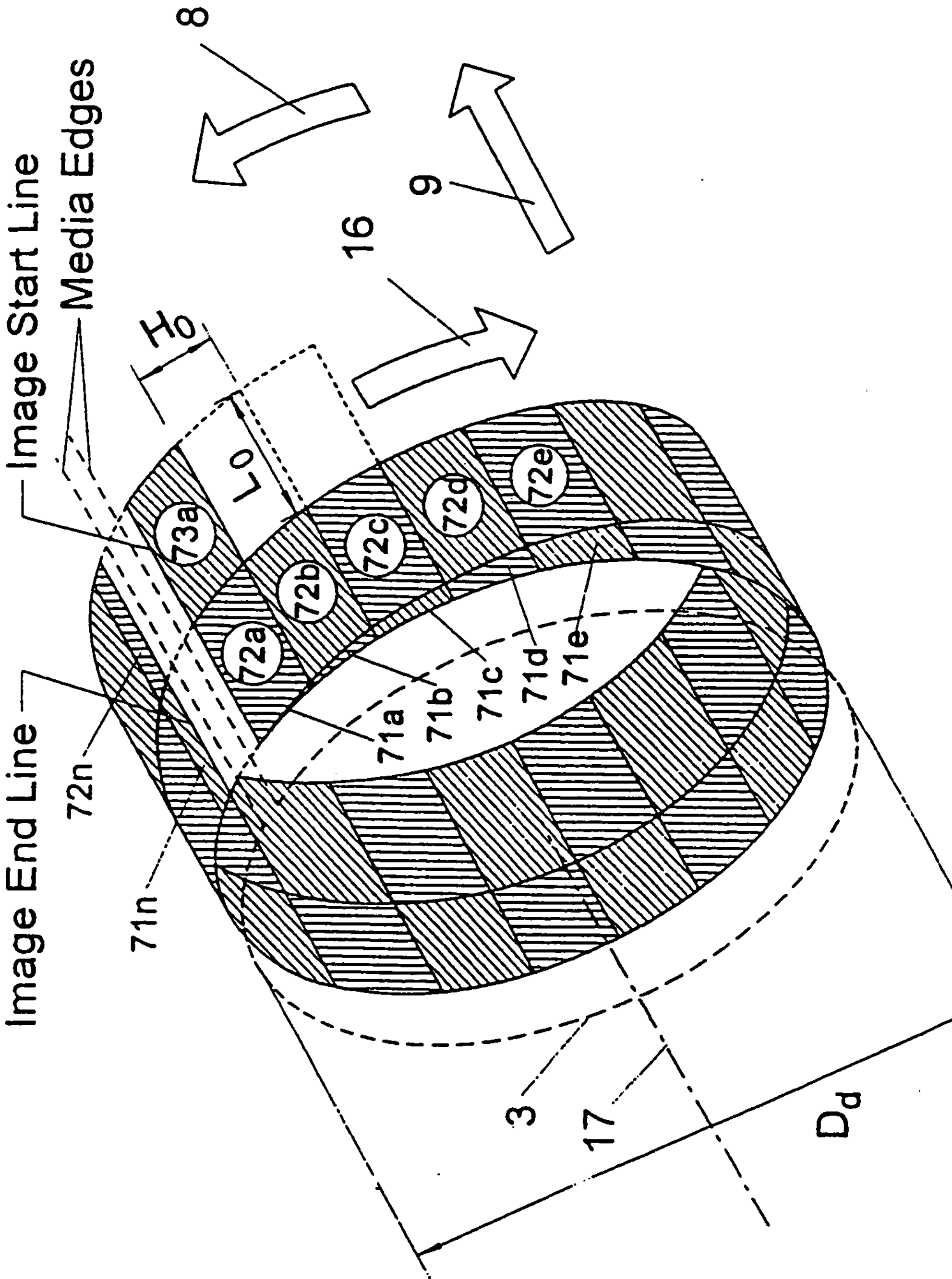


Figure 2b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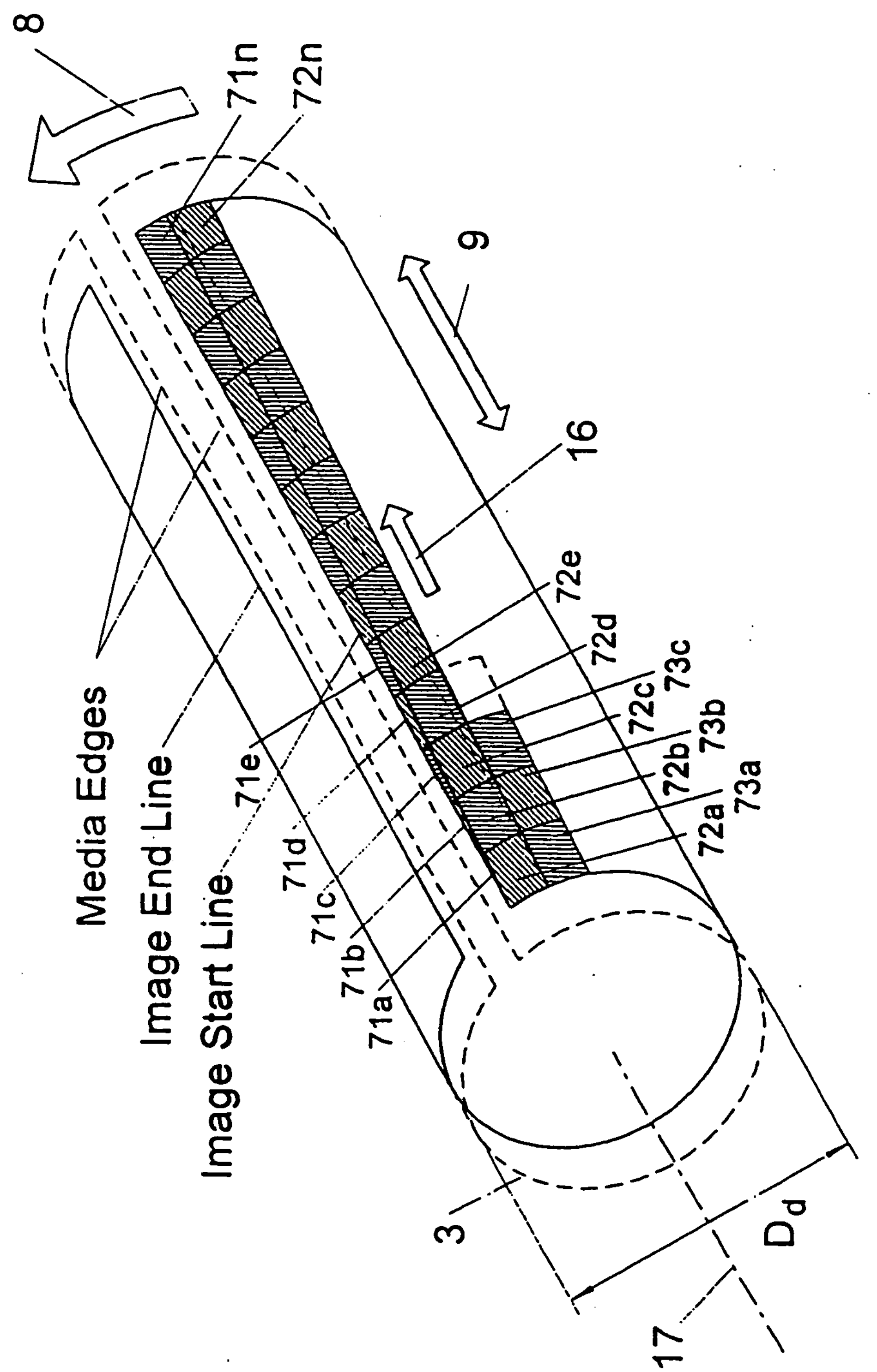
3
17
D_d

Figure 3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17

Figure 4

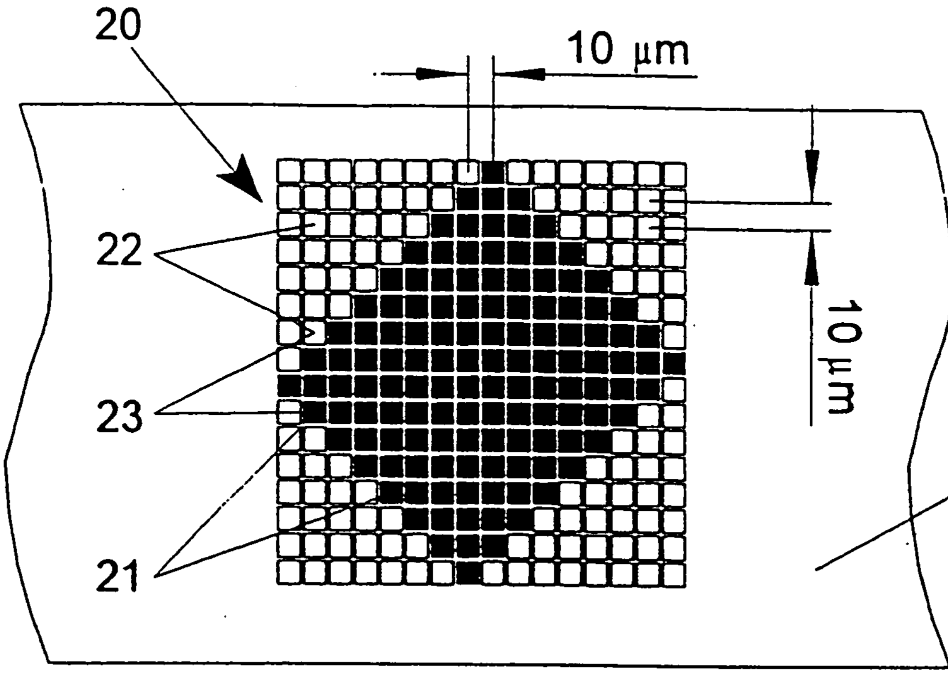


Figure 5a

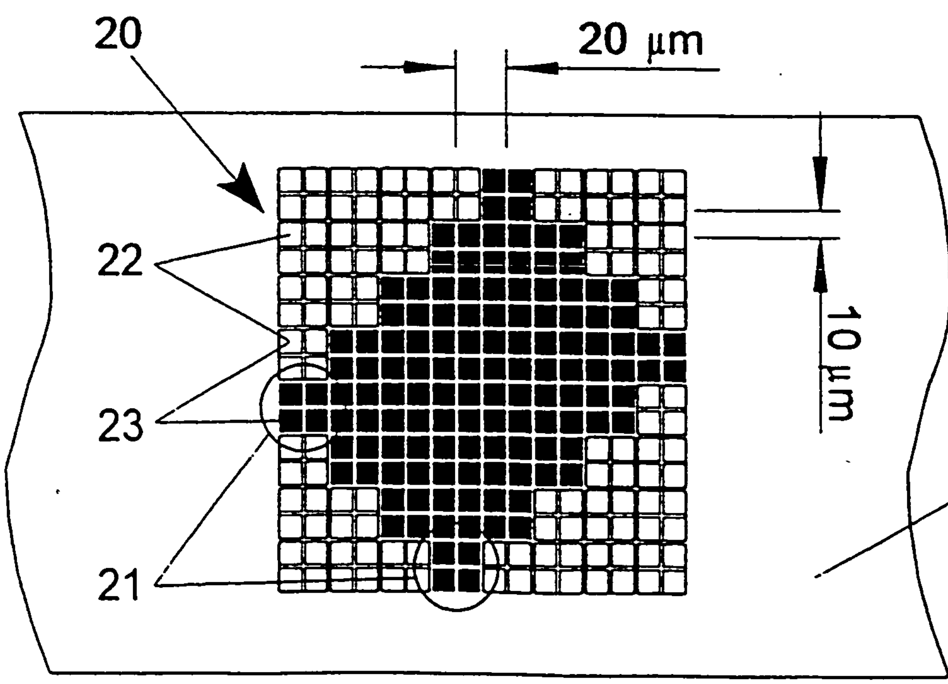


Figure 5b

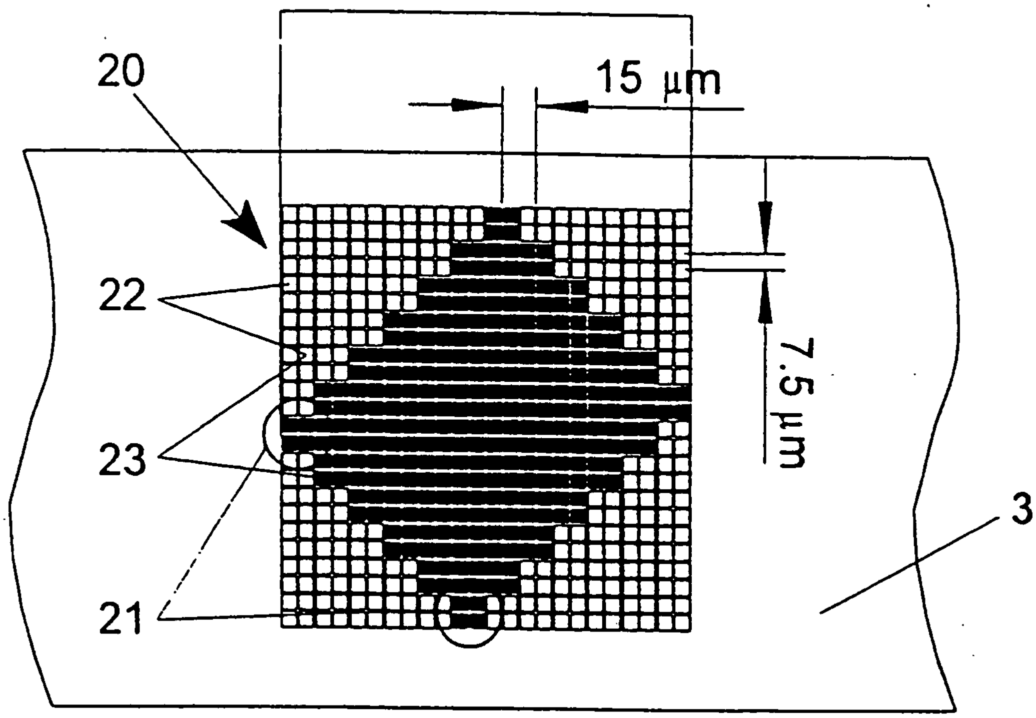
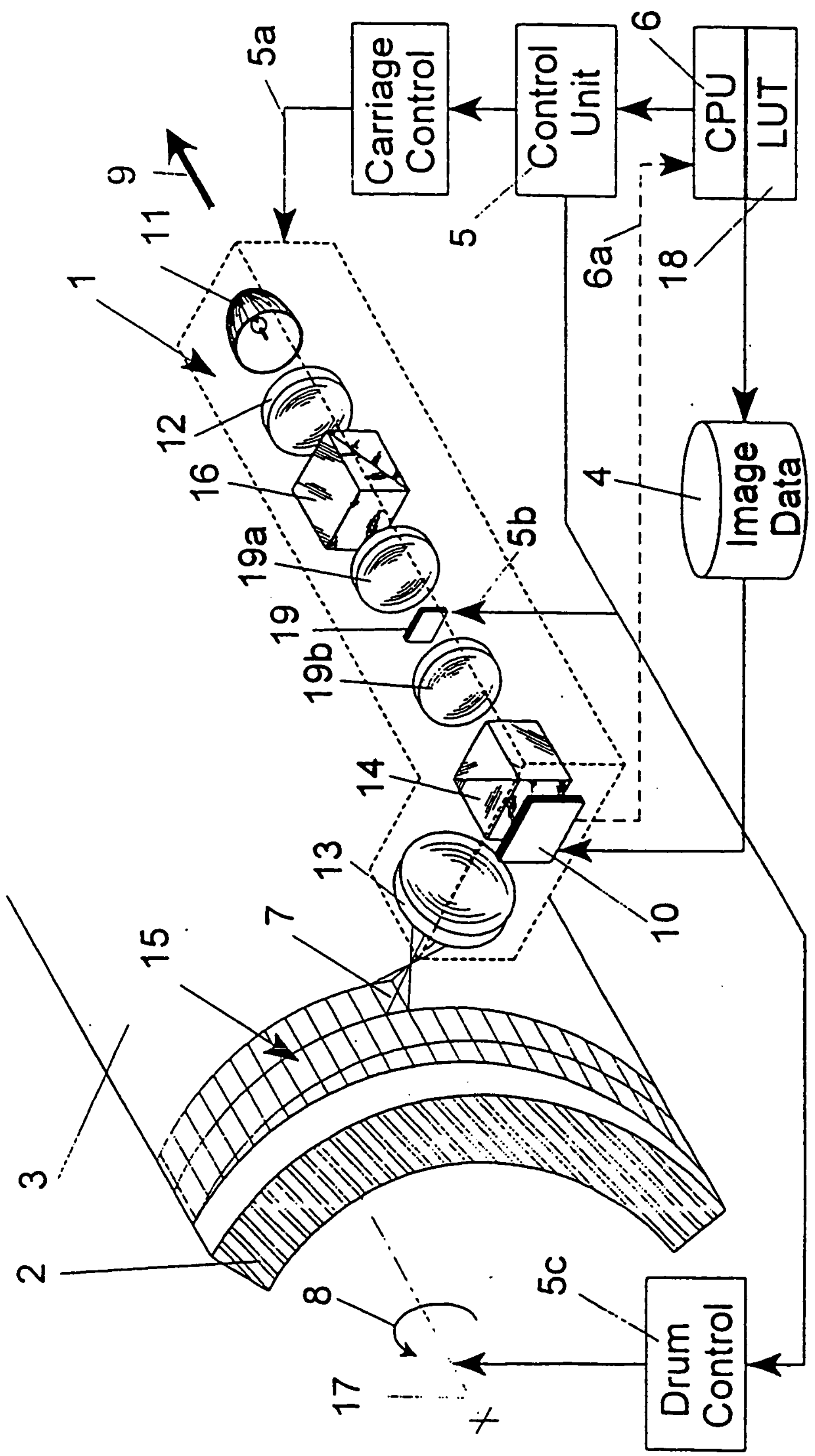


Figure 5c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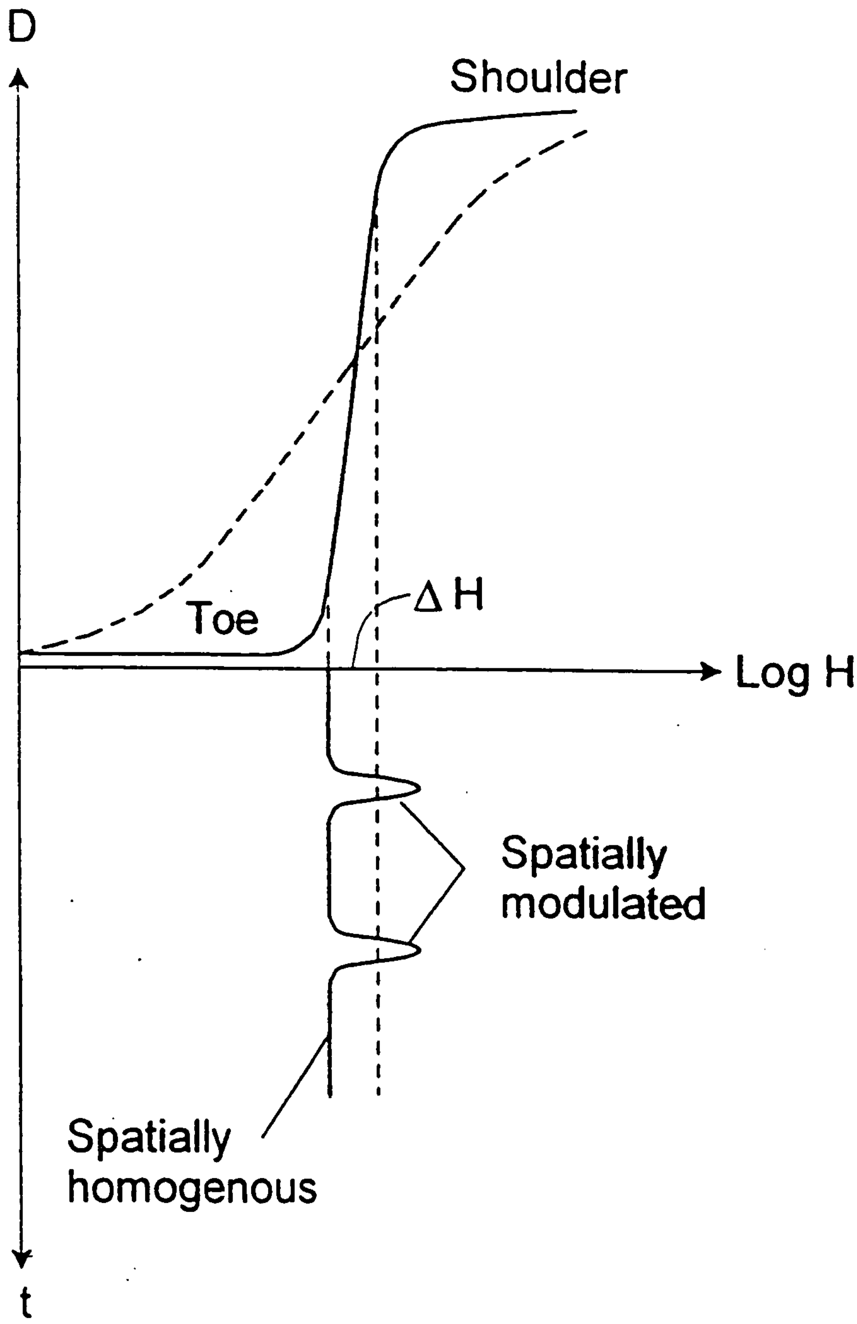
19a
19b

Figure 6


D
Shoulder
Toe
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Log H
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modulated
Spatially
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Figure 7

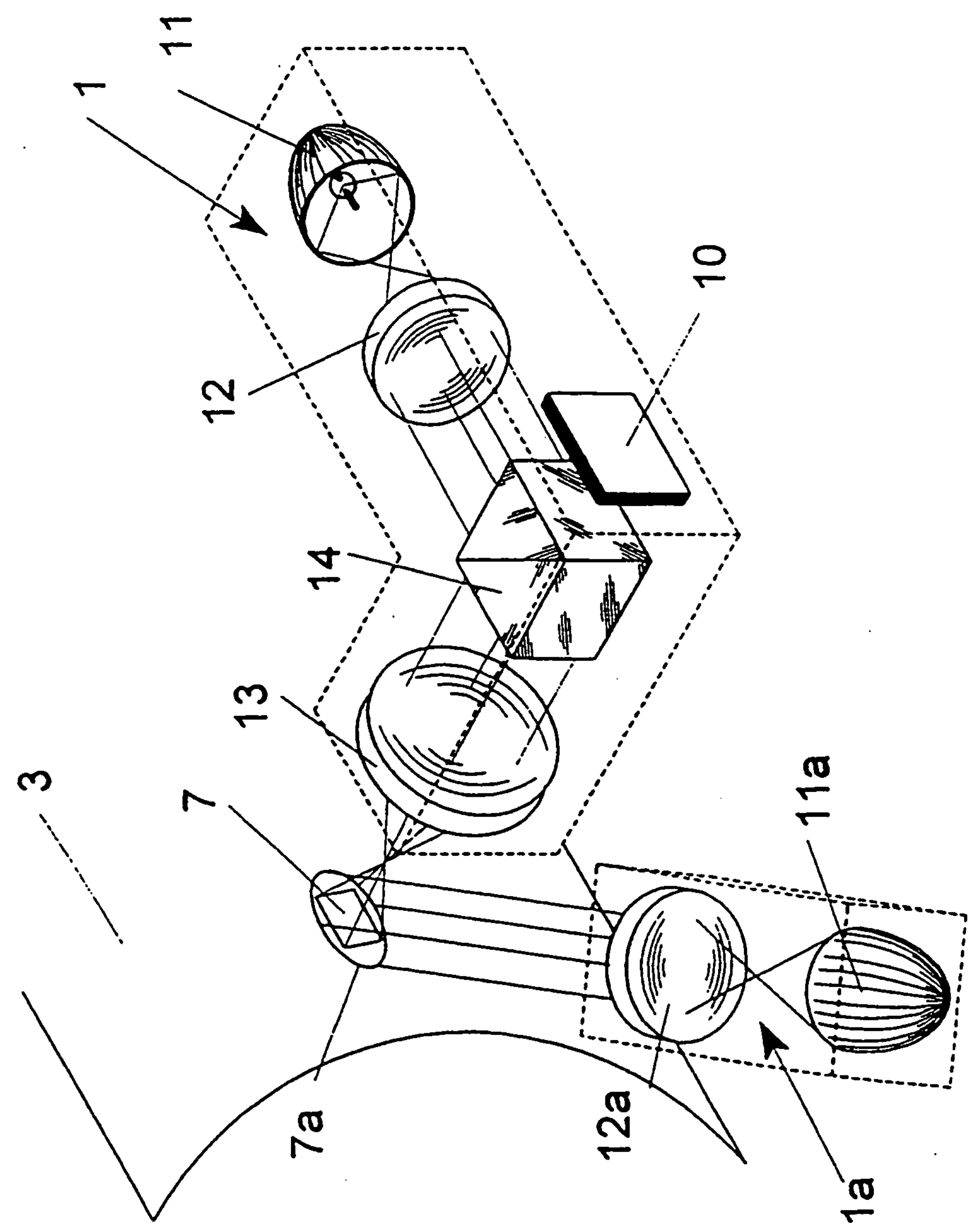

Figure 8